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Title: Test Standards: Displacement Damage

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Test Standards: Displacement Damage

LANL Radiation Effects Summer School

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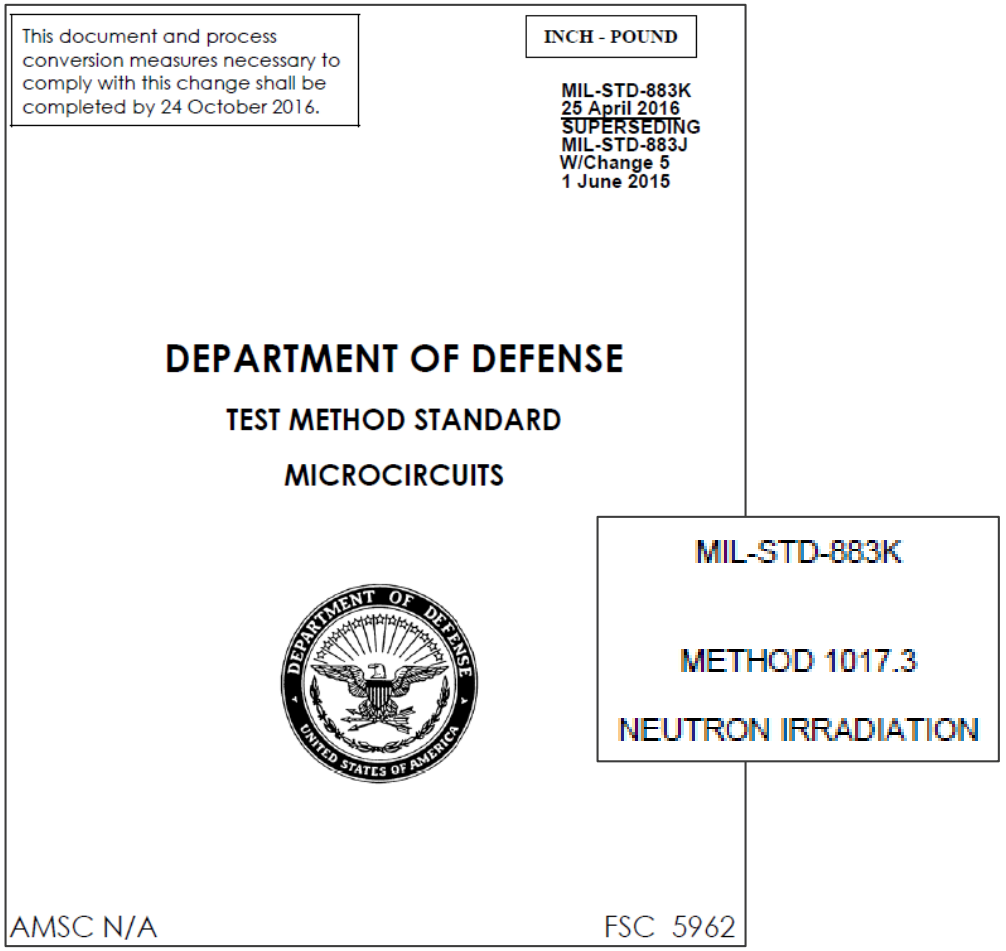
NNSA
National Nuclear Security Administration
Managed by Triad National Security, LLC for the U.S. Department of Energy's NNSA

Overview

- MIL-STD-883K, Method 1017.3: neutron irradiation
  - Objectives
  - Equipment
    - Test instruments
    - Radiation source
    - Dosimetry
  - Procedure
  - Documentation


This document and process conversion measures necessary to comply with this change shall be completed by 24 October 2016.

INCH - POUND

MIL-STD-883K
25 April 2016
SUPERSEDING
MIL-STD-883J
W/Change 5
1 June 2015

DEPARTMENT OF DEFENSE

TEST METHOD STANDARD

MICROCIRCUITS

MIL-STD-883K

METHOD 1017.3

NEUTRON IRRADIATION

AMSC N/A

FSC 5962

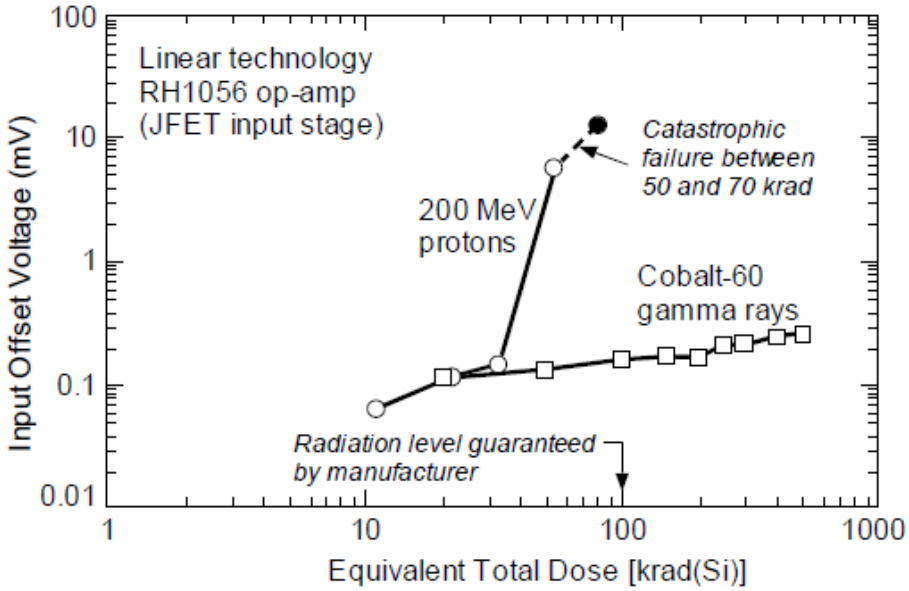
Purpose (Method 1017.3, 1)

Displacement damage neutron tests are destructive.

"Determine the susceptibility of semiconductor devices to non-ionizing energy loss (NIEL) degradation"

- **Objectives**
  - Measure electrical degradation as a function of neutron fluence Φ
  - Determine whether device performance is still acceptable after exposure to fluence Φ

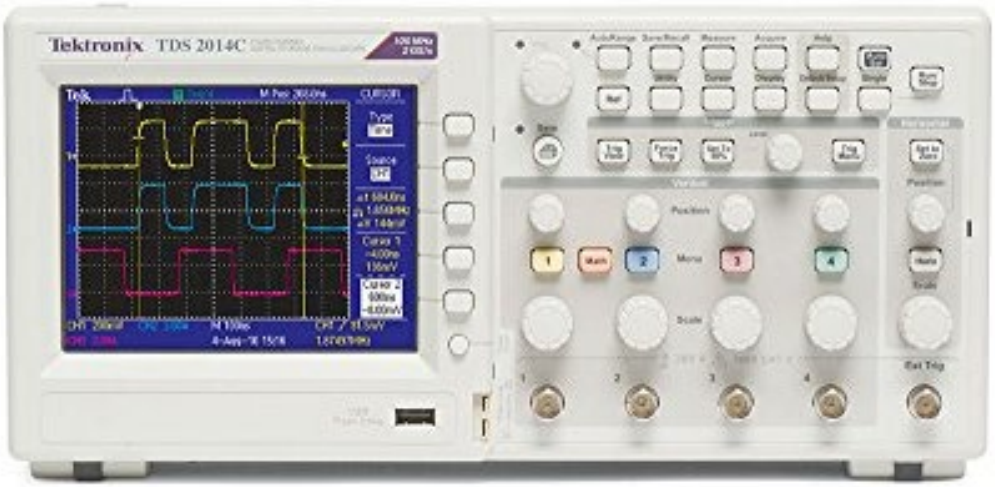
- **Parts to test**
  - Diodes: increased leakage current
  - Transistors:
    - Decreased gain (BJTs)
    - Increased channel resistance (MOSFETs),
  - Integrated circuits:
    - Output voltage changes (voltage regulators)
    - Increased offset voltage (op amps)



After Rax, Johnston, and Miyahira, *TNS* 46, 1999

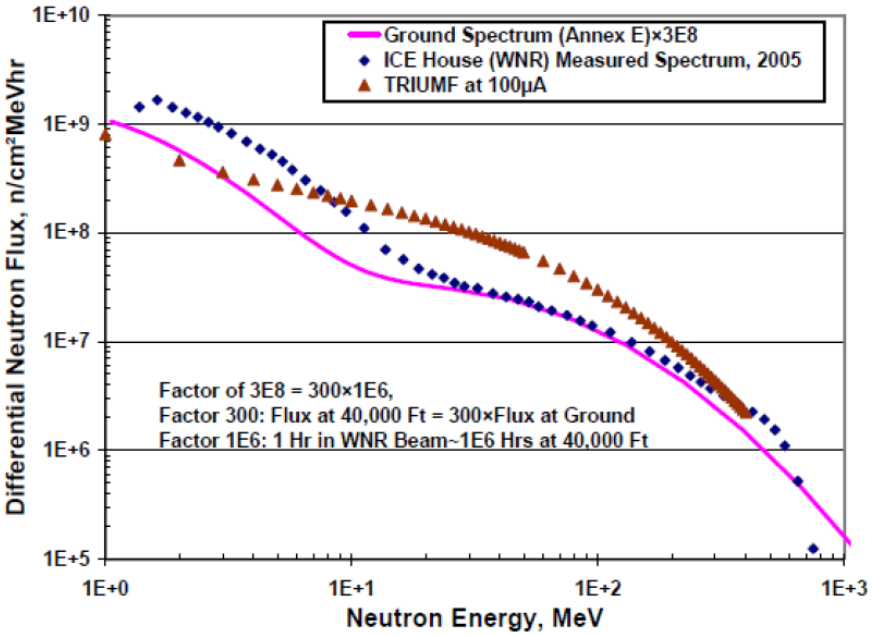
Apparatus: Test instruments (Method 1017.3, 2.1)

- **Test instruments:** equipment needed to measure degradation in specific electrical parameters as a function of fluence Φ
  - Power supplies
  - Multimeters, digital voltmeters, picoammeters
  - Parameter analyzers



Apparatus: Radiation source (Method 1017.3, 2.2)

- **Radiation source:** well-characterized neutron source
  - Broad energy spectrum: fast burst reactor, unmoderated tungsten spallation source
  - Monoenergetic: deuterium-deuterium (DD) or deuterium-tritium (DD) generators
  - **Note:** ionizing radiation must be characterized before the test; don't use sources that generate total ionizing dose greater than 500 rad(Si) per 1×10^{12} n/cm^3

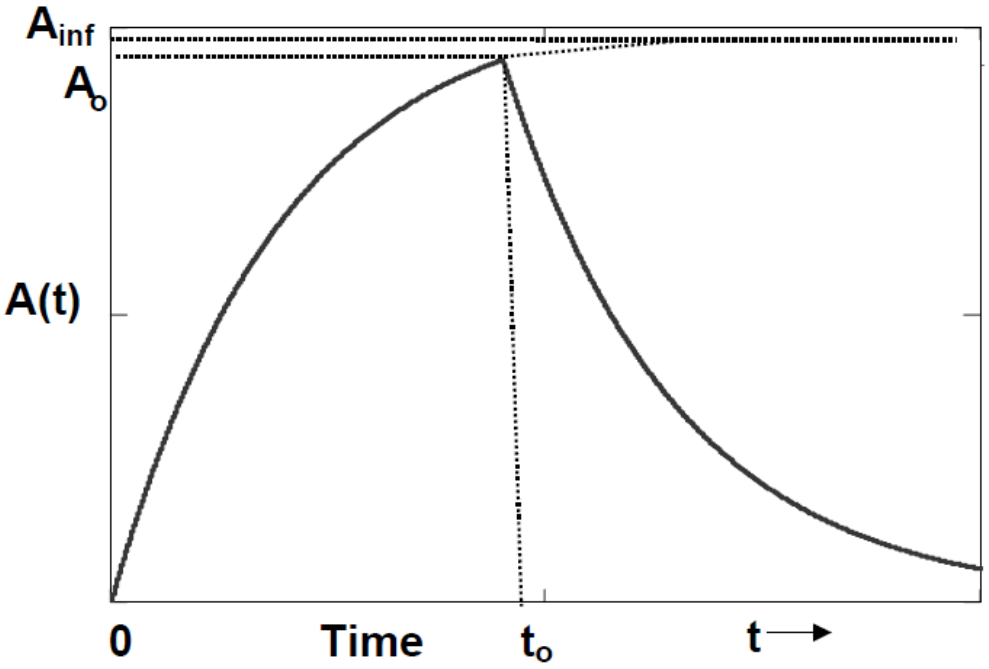


WNR has an unmoderated tungsten spallation source

Monoenergetic DT neutron generator made by ThermoFisher

Apparatus: Dosimetry equipment (Method 1017.3, 2.3)

- **Dosimetry equipment:** (as required)**:** equipment needed to measure 1 MeV equivalent fluence Φ (note: facility may provide dosimetry)
  - **Fluence:** fast neutron activation foils: ^{32}S, ^{54}Fe, ^{58}Ni plus foil counting equipment
  - **Dose**: thermoluminescence dosimeters (TLDs) plus readout equipment
  - **Note:** energy spectrum of neutrons must be known to use foils; see ASTM E 722 for method to characterize unknown neutron energy spectrum

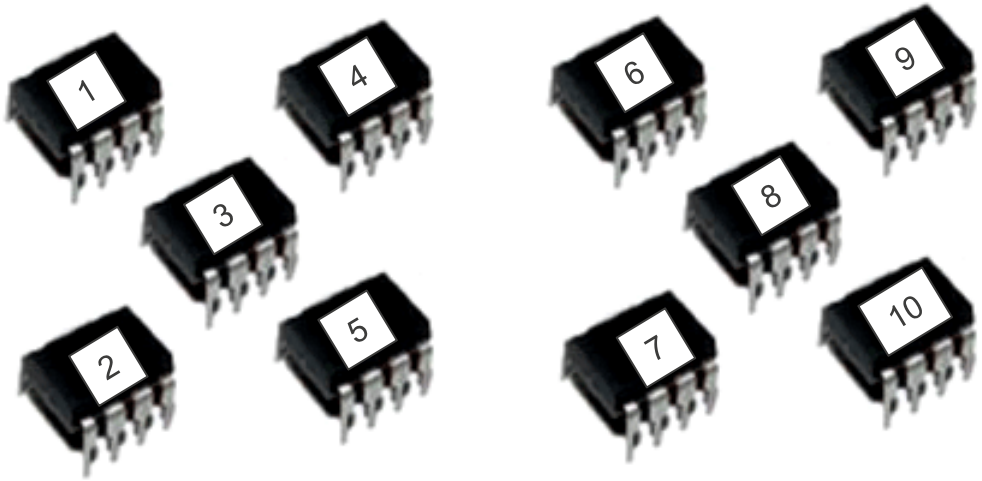


Foil activity vs time, after Knoll, *Radiation Detection and Measurement*, 2000

Procedure: Safety & Part Selection (Method 1017.3, 3.1, 3.2)

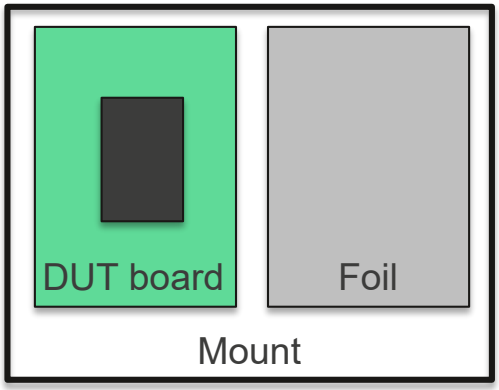
- **Safety:** irradiated parts may be activated; follow radiation facility's health physics or radiation safety regulations for handling and storage

- **Test samples:**
  - **Selection:** randomly select at least **10** parts that meet rated electrical performance
  - **Serialization:** add serial numbers for comparison of pre- and post-exposure data

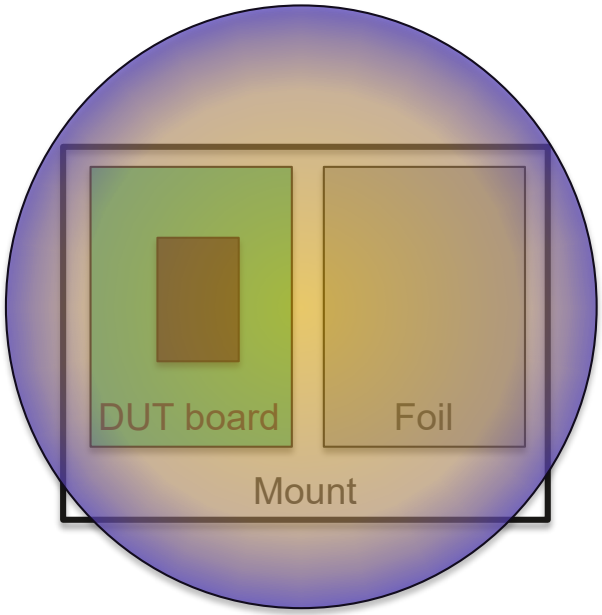


Procedure: Pre-exposure (Method 1017.3, 3.3)

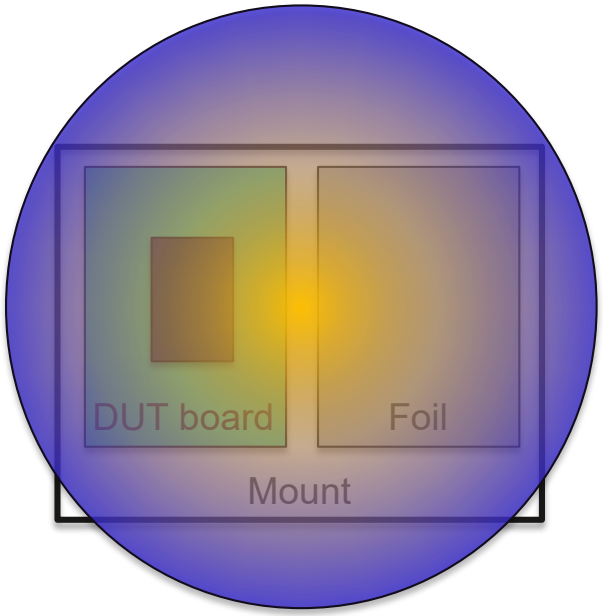
- **Pre-exposure (Method 1017.3, 3.3):**
  - **Electrical tests (Method 1017.3, 3.3.1):** measure and record electrical parameters being evaluated for degradation **before** exposure
  - **Exposure setup (Method 1017.3, 3.3.2):**
    - Mount parts unbiased with all leads shorted OR all leads open (MOS parts must be shorted)
    - Parts and dosimeters should be mounted together
    - Fluence should not vary by more than 20% across mounted parts and dosimeters



Mount: DUT and foil



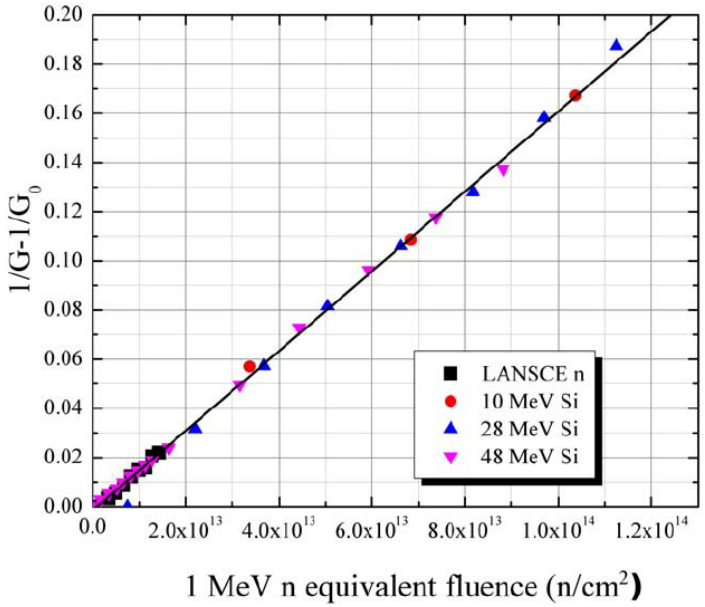
Fluence varies <20% ✔



Fluence varies >20% ✘

Procedure: Exposure (Method 1017.3, 3.4)

- **Exposure:**
  - **Accumulated fluence Φ:**
    - irradiate parts to 1MeV equivalent fluence specified by application requirements
    - Use new set of dosimeters (if required) for each exposure level
  - **Ambient temperature:** 24 °C ± 6 °C
  - **Incidental dose**: use shielding to reduce gamma exposure from neutron source if TID absorbed by part will exceed 10% of part's rated dose value



Inverse gain vs 1 MeV eq. neutron fluence, after Vizkelethy *et al*. SAND2006-7746, 2006

JANSM

Reliability Level

JANSM – 3K Rads (Si)
JANSD – 10K Rads (Si)
JANSP – 30K Rads (Si)
JANSL – 50K Rads (Si)
JANSR – 100K Rads (Si)
JANSF – 300K Rads (Si)

Example of Joint Army Navy ("JAN") parts with markings indicating reliability to different total doses

Procedure: Post-exposure (Method 1017.3, 3.5)

- **Electrical tests (Method 1017.3, 3.5.1):**
  - Select parts for electrical tests
  - Measure and record electrical parameters being evaluated for degradation
- **Anomaly investigation (Method 1017.3, 3.5.2):**
  - Identify parts exhibiting anomalous behavior (e.g., non-linear degradation)
  - Perform failure analysis on these parts per method 5003, MIL-STD-883
    - **Goal:** identify failure mechanism (electrical, mechanical, chemical)
    - **Data** to provide to failure analysis investigation:
      - **Test conditions**: type of test, how long part was in service, temperature, stress conditions during failure
      - **System conditions:** location of failure in equipment, date, identification of test or inspection when failure was noted, unusually environmental conditions or system anomalies, equipment symptoms
      - **General device info:** part type numbers, serial numbers, date code, size of production or inspection lot (if available), any other identifying info

Documentation: Request (Method 1017.3, 4)

- **Request for test:**
  - Part types
  - Quantity of parts to test
  - Electrical parameters to measure in pre- and post-exposure tests
  - Criteria for pass, fail, and record actions on tested parts
  - Criteria for anomalous behavior designation
  - Radiation exposure levels
  - Test instrument requirements
  - Radiation dosimetry requirements (if other than foils and TLDs)
  - Ambient temperature (if other than 24 °C ± 6 °C)
  - Requirements for data reporting and submission

Documentation: Report (Method 1017.3, 3.6)

- **Report:**
  - Part information:
    - Part type number
    - Serial number
    - Manufacturer
    - Controlling specification
    - Date code
    - Any other identifying information provided by manufacturer
  - Test data sheet(s):
    - Radiation test date
    - Electrical test conditions
    - Radiation exposure levels
    - Ambient conditions (temperature, humidity, pressure as applicable)
    - TEST DATA
    - Any parameter measurement circuits used other than those specified
    - Anomalous incidents during test (in footnotes to data)